

THREE-PANEL COLOR MANAGEMENT SYSTEMS AND METHODS

Priority Claim and Related Applications

[0001] The present application is a continuation-in-part application from and claims priority to U.S. Application Serial No. 10/000,227 filed November 30, 2001 and U.S. Application Serial No. 10/294,426 filed November 14, 2002 both entitled "Compensated Color Management Systems and Methods," both applications having Jianmin Chen, Michael G. Robinson, Jonathon R. Birge, and Gary D. Sharp, as inventors, and having as assignee ColorLink, Inc., the assignee of the present application. These applications are incorporated herein by reference in their entirety for all purposes.

Field of the Invention

[0002] The present invention relates generally to color management in projection displays and, more particularly, to color management architectures for three-panel projection systems that utilize color selective polarization filters (CSPF) and polarizing beam splitting (PBS) elements.

Background

[0003] It is generally desirable for projection systems to produce high quality images while being compact and inexpensive. In prior art transmissive systems using polysilicon liquid crystal panels, high contrast is achieved by situating each panel between crossed sheet polarizers. Color management beam splitters/combiners and other optics are external to these units, insuring that polarization is not contaminated and contrast degraded.

[0004] In projection systems using reflective panels, such as liquid crystal on silicon (LCOS) displays, beam routing is frequently accomplished using polarizing beam splitters. PBSs are

four-port devices, comprising an input port, an output port, and a reflective panel port, with the fourth port typically unused. The behavior of thin-film PBS cubes, for instance, is such that s-polarized light is reflected, while orthogonal, p-polarized light is substantially transmitted.

[0005] A number of four-panel or "quad" architectures have been described in prior applications such as U.S. Patent Application Serial Nos. 09/ 736,105, and 10/294,426, for the separation, modulation, and re-combination of three primary colors. These functions may be accomplished using new architectures for color management that are described in the present application.

Summary

[0006] The present invention relates to color management architectures in video projection systems. Specifically, the described architectures employ three polarizing beamsplitter cubes (PBSs) and a dichroic beamsplitter to achieve color separation and recombination of red, green and blue primary color bands to illuminate and project light from three reflective video display panels. Color separation and recombination with the PBSs is achieved through polarization encoding of the separate color bands by color selective polarization filters. These architectures further provide for systems in which the constituent PBSs are used to analyze the reflected light and which do not require external polarizing elements for light analysis. Two of the three display panels are analyzed in transmission by their neighboring PBSs, whereas the third panel, which shares a PBS with another, is analyzed in transmission by the output PBS.

[0007] For the above-described color management architectures, the three display panels are placed in an 'L' shaped three cube assembly whose output port is defined. Unlike prior three-panel/three-PBS architectures, which "notch" out the green spectrum from between the red and

blue spectrums for individual manipulation by a PBS/display panel couplet, *see, e.g.*, U.S. Patent Application No. 2002/0001135, certain of the present architectures separate either blue or red first, leaving colors from adjacent wavelength bands to be manipulated between two panels by a single PBS. To accomplish this management of adjacent color bands through a single PBS, the present application recognizes the ability to mismatch color selective polarization filters to avoid color cross-talk in the region between the adjacent color bands. This allows blue light, for example to be treated separately to improve its contrast, which is an advantage because in many color management systems, blue contrast is often the most difficult to control. Other advantages of routing colors of adjacent wavelength bands to be manipulated between two panels by a single PBS include being able to tailor more effectively the PBS performance to the color bands that are then continuous in wavelength.

[0008] In addition to the adjacent color management techniques described above, the present invention can incorporate skew-ray compensating filters, such as described in commonly owned U.S. Patent Appl. No. 10/000,227, which is incorporated by reference in the present application. The use of these skew-ray compensating filters in the disclosed, particularly between adjacent PBSs and particularly in physically compact, high angle illumination (low $f/\#$) implementations, can increase system performance.

Brief Description of the Drawings

[0009] FIGURE 1 shows an exemplary prior art "quad" color management system;

[0010] FIGURE 2A shows an exemplary color management architecture for a projection system that includes a dichroic input beam splitter with polarizers;

[0011] FIGURE 2B shows the exemplary projection device 1300 of FIGURE 2A with optional additional trim filters in place of polarizers;

[0012] FIGURE 2C shows the exemplary projection device 1300 of FIGURE 2A with a combination of polarizers and extra trim dichroic filters;

[0013] FIGURE 3 illustrates a projection device that includes a dichroic input beam splitter with an output quarter-wave plate to compensate for reflection from a projection lens;

[0014] FIGURE 4 is an exemplary variation of the projection device shown in FIGURE 3 including extra trim dichroic filters;

[0015] FIGURE 5 is another exemplary variation of the projection device shown in FIGURE 3 with a magenta/green filter for the yellow port;

[0016] FIGURE 6 illustrates yet another exemplary variation of the projection device shown in FIGURE 3 with o-plates for skew ray compensation; and

[0017] FIGURE 7 shows an exemplary variation of the projection device of FIGURE 3 with light input at 90 degrees.

Detailed Description

[0018] FIGURE 1 shows an exemplary prior art "quad" color management system 300. In the system 300, an s-polarized white light 320 is incident on a first CSPF 304 that converts light of a first spectrum to the orthogonal polarization that is subsequently transmitted through the first PBS 306. Light that is complementary to the first spectrum remains s-polarized and is subsequently reflected by the first PBS 306. Light having the first spectrum is then transmitted by a second PBS 308 and is subsequently incident upon a first reflective panel 310, which includes an optional quarter-wave plate 312. In the ON-state, light reflected from the first reflective panel 310 is converted from p-polarization to s-polarization, thereby enabling the second PBS 308 to reflect the light through a first 0-oriented half-wave plate 314. The light is

then reflected by a third PBS 316. The third PBS 316 reflects the first spectrum into a second CSPF 319, which converts light of the first spectrum to p-polarization, which it is then analyzed by a clean-up polarizer 324.

[0019] The incident light 302 of a second and third spectrums is reflected by the first PBS 306 onto a first compensating color selective polarization filter (CCSPF) 322, which reflects the state of polarization (SOP) of the second spectrum about a $\pm\pi/4$ axis. Light of the second spectrum is transmitted through a fourth PBS 324 to a second reflective panel 326, which includes an optional quarter-wave plate 328. The first CCSPF 322 retains the SOP of the third spectrum. The third spectrum is subsequently reflected by the fourth PBS 324 to a third reflective panel 330, which includes an optional quarter-wave plate 332. In ON-state, light reflected from the second and third reflective panels 326, 330 returns to the PBS 324 with orthogonal states, so that light in the second and third spectra is incident on a second CCSPF 334. The second CCSPF 334 reflects the SOP of the second spectrum about a $\pm\pi/4$ axis, thus restoring both spectra to p-polarization. The p-polarized light is then transmitted by the third PBS 316, the second CSPF 318 and the clean-up polarizer 324. The optional quarter-wave plates situated between each panel and PBS are configured to provide skew ray correction.

[0020] **FIGURE 2A** illustrates an exemplary color management architecture for a projection device 1300. The projection device 1300 includes a dichroic input beam splitter 1302 and three PBSs 1104, 1106, and 1108. The PBS may be conventional cube PBSs, Moxtek wire grid polarizers, or any other suitable PBS. The projection device 1300 further includes a first CSP 1112 placed between the dichroic input beam splitter 1302 and the PBS 1106, a second CSP 1114 placed between the PBSs 1106 and 1108, a half-wave plate 1120 orientated at 45° placed between the PBSs 1104 and 1108. A first reflective panel 1122, a second reflective panel 1124,

and a third reflective panel 1126 are configured to modulate a polarized input light beam 1128 to produce an output light beam 1130. All panels can include compensating elements such as quarter-wave plate.

[0021] The projection device 1300 further includes polarizers 1320 and 1322 at the output ports of the dichroic input beam splitter 1302. In one embodiment, the half-wave plate 1120 can be configured to rotate the polarization of the light modulated and reflected by the reflective panel 1124. In some embodiments, a color filter can be added to the half-wave plate 1120. Alternatively, the color filter can substitute the half-wave plate 1120.

[0022] The input light beam 1128 can be polarized or unpolarized and may be generated by any suitable light source, including, but not limited to an ultra-high pressure mercury (UHP) lamp, a xenon lamp, a fusion lamp, a light source according to application 60/358,517, which is incorporated herein in its entirety by this reference, or any other suitable light source. The light source also may include suitable illumination optics. The input light beam 1128 is incident upon the dichroic input beam splitter 1302, which reflects light of a first spectrum and transmits light of a second spectrum.

[0023] The reflected first spectrum of light is then incident upon the PBS 1104, which reflects and directs the first spectrum of light to be incident upon the reflective panel 1124. The reflective panel 1124 modulates and reflects the first spectrum of light. The modulated first spectrum of light then travels through the PBS 1104 and the half-wave plate 1120 oriented at 45°. The half-wave plate 1120 rotates the polarization of the modulated first spectrum of light to the orthogonal polarization direction such that the PBS 1108 will reflect the modulated first spectrum of light. The PBS 1108 reflects and directs the modulated first spectrum of light to

form part of the output light beam 1130. The output light beam may be projected by any suitable projection optics or may otherwise be imaged for display.

[0024] The second spectrum of light, which is transmitted through the dichroic input beam splitter 1302, is incident upon the polarizer 1322 and the CSP 1112. The CSP 1112 rotates part of the second spectrum such that the PBS 1106 will reflect a first portion of the second spectrum of light to the reflective panel 1124 and allow a second portion of the second spectrum of light to be transmitted through the PBS 1106 to the reflective panel 1128. The reflective panel 1124 modulates and reflects the first portion of the second spectrum of light back through the PBS 1106 to the CSP 1114. The CSP 1114 does not rotate polarization of the light reflected from the reflective panel 1124 such that the light will be transmitted through the PBS 1108 and become part of the output light beam 1130. The reflective panel 1126 modulates and reflects the second portion of the second spectrum of light back into the PBS 1106, which reflects the light from the reflective panel 1126 toward the CSP 1114. The CSP 1114 rotates polarization of the light reflected from the reflective panel 1126 such that the light will be transmitted through the PBS 1108 and become part of the output light beam 1130. The CSP 1114 can be further configured to compensate the light reflected from the reflective panels 1126 and 1128 for skew rays.

[0025] The wavelengths of light in the transition region between the first and second portions of the second reflected light beam are defined in the absence of any external notch filtering by the transitions of filters 1112 and 1114. In the case where the second reflected beam has a continuous spectrum, e.g. the yellow 520-680nm band, the transition slopes of the individual filters 1112 and 1114 that separate the red wavelengths (>600nm) from those that are green (<570nm) should not overlap significantly (<10%) to avoid low contrast with transition light

(~570-600nm) always directed towards panel 1126. This implies that the yellow transition of the filter 1112 should be at a longer wavelength than that of filter 1114 in this exemplary case.

[0026] **FIGURE 2B** shows the exemplary projection device 1300 of FIGURE 2A with optional additional trim filters 1304 and 1306 in place of the polarizers 1320 and 1322 at the output ports of the dichroic input beam splitter 1302. The trim filters 1304 and 1306 improve the color saturation. The input light 1308 can be primarily of a single polarization state.

[0027] **FIGURE 2C** shows the exemplary projection device 1300 of FIGURE 2A that includes both the polarizers 1320 and 1322, and extra trim dichroic filters 1304 and 1306 at the output ports of the dichroic input beam splitter 1302.

[0028] **FIGURE 3** illustrates a projection device 1350, which is an exemplary variation of the projection device 1300 shown and described in FIGURE 2. An input light 1308 enters into the projection device 1350 from the left side of the dichroic input beam splitter 1302. In the present example, the dichroic input beam splitter 1302 is configured to transmit the blue spectrum and reflect the yellow spectrum. However, the dichroic input beam splitter 1302 can be configured to reflect and transmit any desired combination of spectra. For projection devices with modest f-number, such as $f/2.8$, additional extra trim dichroics, such as 1304 and 1306, may not be necessary. In the present example, the projection device 1350 is configured for $f/2.8$. Typically, dichroic beam splitters, such as dichroic input beam splitter 1302, do not preserve the polarization of the input light. Thus, to preserve the polarization of the input light 1308 or to allow operation with unpolarized input light 1308, polarizers 1320 and 1322 are placed at the output ports of the dichroic beam splitter 1302. Additionally, the trim filters 1304 and 1306 can also be placed at the output ports of the dichroic input beam splitter 1302 such as shown in FIGURE 2C.

[0029] A red/cyan filter 1112 processes the reflected yellow spectrum. The red/cyan filter 1112 transforms the polarization state of red light while substantially maintaining that of cyan. A reflective panel 1128 modulates the red spectrum and a reflective panel 1126 modulates the green (and any blue) spectrum. A magenta/green filter 1114 transforms the polarization of red and green spectra at the output of the polarizing beam splitting element 1106, rotating the red (and any blue) light and leaving substantially unaffected the green light. An achromatic quarter-wave plate 1326 rotated at 45 degrees is placed at the output port of the polarizing beam splitting element 1108. A filter 1324 can be placed between the polarizing beam splitting elements 1104 and 1108. The filter 1324 rotates the polarization of the blue spectrum and does not affect the yellow spectrum. As explained below, filter 1324 functions in combination with a quarter-wave plate to improve the ANSI contrast. According to one embodiment, the quarter-wave plate 1326 can be achromatic over the visible spectrum.

[0030] "ANSI contrast," is a performance metric for comparing the contrast between a light part of a display and a dark part. The problem monitored with ANSI contrast measurement is the reflection back into a projection system of light from portions of a panel that correspond to bright areas in the display. Typically, the light coming off the bright areas of the panel can be reflected back into the projection device and light up the dark areas of the panel, which can result in increasing the intensity of the display's dark areas. One solution to avoid the unwanted reflections is to change the polarization of the reflected light. In the present example, when a part of the green panel is bright and a part of it is dark, the projected green light from the bright areas of the panel heads towards the projection lens (not shown) and is reflected back from the surfaces of elements within the projection lens. If the reflected green light has the same polarization as the incident light, then it travels back to the green panel where it can illuminate

dark regions of the green panel with the incorrect polarization. This light can then be projected onto the screen, increasing the light level of the dark display regions and reducing ANSI contrast. To a viewer, low ANSI contrast results in a "washed out" appearance.

[0031] For example, to prevent green reflected light from hitting dark parts of any panel, the quarter-wave plate 1326 is able to alter the polarization of reflected light to be primarily s-polarized. This results in most of the green light being directed out of the system and away from any panel. When the projected green light exits the polarizing beam splitting element 1108, it is turned into predominantly circularly polarized light by the quarter-wave plate 1326. When the circularly polarized light is reflected off the projection lens and passes back through the quarter-wave plate 1326, the polarization of the reflected, opposite handedness predominantly circularly polarized light is changed to be substantially s-polarized. The s-polarized reflected light does not transmit through the output polarizing beam splitter 1108 and is reflected downwards towards the blue panel 1124. The filter 1324 is configured to rotate the polarization of the blue spectrum and leave green and red substantially unchanged. In the present example, the s-polarized reflected light is green light, thus, the filter 1324 does not rotate its polarization and the polarizing beam splitting element 1104 then prevents this s-polarized reflected light from striking the blue panel 1124. In this specific embodiment reflected red light is similarly prevented from striking a panel. Reflected blue light incident on panels can often be tolerated due to its relatively low perceived brightness. In the case where projection lenses are low in reflection the quarter wave may not be necessary and the filter 1324 may be replaced with a half-wave plate at 45 degrees.

[0032] **FIGURE 4** illustrates a projection device 1360, which is an exemplary variation of the projection device 1350 shown in **FIGURE 3**. In the present example, the projection device

1360 is configured for an f-number that is less than or equal to $f/2.8$. Because of the low f-number and higher angles, the dichroic filter 1302 at the input begins to transmit some yellow and reflect some blue. Thus, to avoid color leakage at the output ports, additional extra trim dichroic filters 1328 and 1330 are added at the yellow and blue output ports of the dichroic beam splitter 1302 respectively. The extra trim dichroic filter 1328 can be configured to filter out the blue leakage in the yellow spectrum and the extra trim dichroic filter 1330 can be configured to filter out yellow leakage in the blue spectrum.

[0033] **FIGURE 5** shows a projection device 1370, which is yet another exemplary variation of the projection device 1350 shown in **FIGURE 3**. The projection device 1370 includes a magenta/green filter 1335 in the yellow output port of the dichroic beam splitter 1302. In the present example, the magenta/green filter 1335 replaces the red/cyan filter 1112 of the projection device 1350 of **FIGURE 3**. The magenta/green filter 1335 can improve the manufacturability and the cost of the projection device 1370. When the magenta/green filter 1335 is used in the projection device 1370, the extra trim dichroic filters 1328 and 1330 can be added at the output port of the dichroic beam splitter 1302. In the projection device 1350 of **FIGURE 3**, the dichroic beam splitter 1302 typically reflects some of the blue light. The red/cyan filter 1112 causes the reflected blue light to be reflected a second time by the polarizing beam splitter 1106, and the blue light heads to the green panel 1126.

[0034] The performance of the green panel 1126 does not noticeably degrade due to the blue leakage as the blue light is filtered out of the system by a combination of the magenta/green filter 1114 and the output analyzing PBS 1108. However, when the red/cyan filter 1112 is replaced by the magenta/green filter in the projection device 1370, the reflected blue light is directed to the red panel 1128. The reflected blue light can adversely affect the performance of the red panel

1128. Thus, the extra trim dichroic filter 1328 is added to filter out the reflected blue. The projection system 1370 can be used for application with any f-number.

[0035] **FIGURE 6** illustrates a projection device 1380, which is yet another exemplary variation of the projection device 1350 shown in FIGURE 3. In the present example, the projection device 1380 includes two oblique-plate (o-plate) compensators 1340 and 1345 for skew ray compensation. The contrast of a projection system begins to degrade when the f-number of the application goes below $f/2.5$ because there is no compensation for the off-axis geometrical rotation of the polarization axes of the polarizing beam splitters 1106 and 1104. The o-plate compensators 1340 and 1345 are used to compensate for low f-number illumination. The o-plate compensators 1340 and 1345 provide skew ray compensation. The number of o-plate compensators in each channel depends upon the angle of the incident light. Wider angles may require more than one o-plate compensator in each channel, while other systems may demand higher performance in one of the two reflected paths necessitating only one o-plate. In the case of an isolated blue channel, where the dichroic beam splitter 1302 reflects yellow light, the green contrast can be improved by placing an o-plate compensator at the input port of PBS 1106.

[0036] In projection systems that use cubes as beam splitting elements, there exists a geometric symmetry that can be solved by a retarder-based compensation scheme. The compensation components are sandwiched between cubes that have reflecting surfaces that are at 45 degrees to the beam propagation direction, and can be parallel or orthogonal. Retarder based compensators between cubes act to transform polarization through rotation or reflection for the parallel or orthogonal reflecting surface situations respectively. In a four-cube system or a five-cube system, retarder stacks are placed between the cubes and can be used as skew ray compensators if they have these transformation properties. In a three-cube system such as

projection device 1380, this retarder solution can be implemented for the filters 1114 and 1324, which are situated between adjacent cubes. At the input, where input linear polarization is analyzed by a PBS, o-plates can be used to compensate skew rays.

[0037] **FIGURE 7** illustrates an exemplary projection system 1390, which is yet another exemplary variation of the projection device 1350 shown in **FIGURE 3**. In the projection device 1390, the input light 1308 enters the projection device 1390 at 90°. In projection device 1390, the dichroic beam splitter 1302 reflects the blue spectrum and transmits the yellow spectrum. Typically, dichroic beam splitters are better reflectors than transmitters. In the projection device 1390, the dichroic filter 1302 reflects a small portion of yellow spectrum in the blue channel. In the present example, the extra trim dichroic filter 1330 is configured to clean up the blue channel by removing the reflected yellow spectrum. The o-plate compensators 1340 and 1345 can be added to any of the systems shown in **FIGURES 2-7** for skew ray compensation.

[0038] The embodiments described above provide an efficient means of splitting and recombining color channels while maintaining good polarization and high contrast. These embodiments are configured to achieve very high sequential contrast and enhance other system performance criteria such as:

1. ANSI contrast - by reducing reflection surfaces in the projection path;
2. Soft focus -by reducing non-phase flat components and reflecting surfaces in the projection path;
3. The sequential contrast of a color - by isolating the color channel (e.g., blue);
4. Physical compactness - by introducing a 90° angle between input and output transmission axes;
5. Brightness at high white color temperatures - by increasing blue transmission; and

6. Durability - by removing the output absorbing sheet polarizer.

Further embodiments may act to improve upon some or all of these performance criteria.

[0039] The system performance criteria may be improved at the expense of sequential photopic contrast and component specification. Such improvements may be incorporated since PBS cubes with improved transmission of p-polarized light are commercially available and since sequential contrast may not be limiting when compared with off state color and ANSI contrast.

[0040] Exemplary light sources include ultra-high pressure mercury arc lamps with a small arc size such as is available from Ushio, Toshiba, Perkin-Elmer, Phoenix and others. These light sources are rich in green and blue light but are lacking in red light. These or any suitable light source may be used to provide light for the systems discussed above. Additionally, these light sources produce substantial amounts of UV light, which may degrade organic materials such as polycarbonate films. Specific embodiments covered in this patent isolate the blue channel, which is most likely to contain the possibly damaging UV light. In these cases, inorganic half-wave plates such as those made from quartz can be used between PBSs 1104 and 1108 allowing for an organic material free, UV contaminated blue channel. Exemplary embodiments for a reflecting dichroic beam splitter, a yellow transmitting dichroic, a red-cyan filter, a magenta green filter, an output PBS, a blue transmitting dichroic, an input blue polarization rotating filter, a blue PBS, and an output blue polarization filter are listed in the following charts giving typical illumination cone average performances.

DICHROIC BEAM SPLITTER				
Property	Typical	Range	Units	Comments
Glass substrate index	1.52	1.5-2.0	-	BK7.
Size	40x40x1	N/A	mm	
Average reflection of s-polarized blue light (Rs) 430-470nm	99	80-100	%	Averaged over the input illumination ray set.
Average transmission of s-polarized Green light (Ts) 550-570nm	97	95-100	%	
Red Ts 600-680nm	97	95-100	%	
YELLOW TRIM TRANSMITTING DICHROIC				
Property	Typical	Range	Units	Comments
Blue transmission 430-490nm	1	0-2	%	
Green transmission 530-600nm	96	94-100	%	
Red transmission 600-680nm	97	95 - 100	%	
50% transmission	515	505-525	nm	

RED CYAN FILTER				
Property	Typical	Range	Units	Comments
Blue Crossed polarizer - transmission 430-480nm (Bx)	<2	<10	%	Not critical
Gx (530-560nm)	0.5	0-0.7	%	
Rx (615-680nm)	98.5	97-100	%	
Blue parallel-polarizer transmission (Bp)	>95	>90%	%	Not critical
Gp	98	96-100	%	
Rp	98	96-100	%	
Yellow 50% point	600	595-605	nm	
General Comments	This may be a free-standing part with anti-reflective coatings evaporated directly onto the polycarbonate.			

RED GREEN PBS				
Property	Typical	Range	Units	Comments
Glass index	1.85 (e.g., PBH56)	1.5-2.0	-	A low coefficient of optical elasticity reduces stress induced birefringence.
Size	22x22x28	N/A	mm	
Blue Tp 430-520nm	90	80-100	%	Not critical
Yellow Tp 530-680nm	96	94-100	%	
Blue Ts	1	<2	%	Not critical
Yellow Ts 530-680nm	0.1	<0.2	%	

External surfaces	Input and panels ports may be antireflective coated for <0.5% reflection over the visible spectrum.
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MAGNETA GREEN FILTER				
Property	Typical	Range	Units	Comments
Blue Crossed polarizer - transmission 430-480nm (Bx)	Don't care (D/C)	D/C		
Gx (530-560nm)	1	0-2	%	
Rx (615-680nm)	98	97-99	%	
Blue parallel-polarizer transmission (Bp)	D/C	D/C		
Gp	97	96-99	%	
Rp	0.25	0-0.5	%	
Cyan 50% point	520	<530	nm	
Yellow 50% point	570	565-575	nm	
General Comments	This filter may be bonded between glass substrates with conforming glue, such as silicone, and then the glass is bonded to the adjacent PBSs to avoid reflections. Skew ray compensating.			

OUTPUT PBS				
Property	Typical	Range	Units	Comments
Glass index	1.65 (SF2)	1.5-2.0	-	
Size	27x27x34	N/A	mm	
Blue Tp 430-500nm	D/C	D/C	%	
Green Tp 500-600nm	90	85-97	%	
Red Tp 600-680nm	90	85-98	%	
Blue Ts	0.1%	0-0.2	%	
Yellow Ts 500-680nm	D/C			

BLUE TRIM TRANSMITTING DICHROIC				
Property	Typical	Range	Units	Comments
Blue transmission 430-480nm	97	96-99	%	
Yellow transmission 510-680nm	0.5	0-1	%	
50% transmission	485	480-490	nm	

BLUE PBS				
Property	Typical	Range	Units	Comments
Glass index	1.85 (e.g., PBH56)	1.5-2.0	-	A low coefficient of optical elasticity reduces stress induced birefringence.
Size	22x22x28	N/A	mm	
Blue Tp 430-520nm	95	>93	%	
Yellow Tp 520-680nm	D/C			
Blue Ts	0.3	<0.5	%	
Yellow Ts 520-680nm	D/C			
External surfaces	Input and panels ports may be antireflective coated for <0.5% reflection over the visible spectrum.			

OUTPUT BLUE POLARIZATION ROTATING FILTER				
Property	Typical	Range	Units	Comments
Blue parallel polarizer - transmission 430-470nm (Bp)	1	<2	%	
Blue crossed-polarizer transmission (Bx)	97	>95	%	
Yp (540 - 680)	97	95-100	%	
Yx	2	0-4	%	

[0041] Although the exemplary embodiments described herein may be described in reference to specific colors or combinations of colors, it should be understood that other color combinations are also possible. For example, the color filters can be any combination of colors including Red/Blue, Blue/Green, Red/Green, an additive primary and its complementary subtractive primary or any other color pair as system criteria dictate.

[0042] As used herein, rotation is not limited to a pure optical rotation but also includes any transformation that results in optical transformation or other effects that result in apparent optical rotation. For example, a half-wave plate at 45° can transform a linear state into an orthogonal linear state via retardation but not through rotation.

[0043] Although several embodiments and its advantages have been described in detail, it should be understood that changes, substitutions, transformations, modifications, variations, permutations and alterations may be made therein without departing from the teachings of the present application, the spirit and the scope of the invention being set forth by the appended claims. Further, the reference in this application to "Invention" in the singular should not be used to argue that there is a single point of novelty claimed in this application. Multiple inventions may be set forth according to the limitations of the multiple claims associated with this patent specification, and the claims accordingly define the invention(s) that are protected thereby. In all instances, the scope of the claims shall be considered on their own merits in light of the specification but should not be constrained by the reference to "Invention" included in this application.

[0044] Realizations in accordance with the present invention have been described in the context of particular embodiments. These embodiments are meant to be illustrative and not

limiting. Many variations, modifications, additions, and improvements are possible.

Accordingly, plural instances may be provided for components described herein as a single instance. Boundaries between various components, operations and data stores are somewhat arbitrary, and particular operations are illustrated in the context of specific illustrative configurations. Other allocations of functionality are envisioned and may fall within the scope of claims that follow. Finally, structures and functionality presented as discrete components in the exemplary configurations may be implemented as a combined structure or component. These and other variations, modifications, additions, and improvements may fall within the scope of the invention as defined in the claims that follow.

[0045] The section headings in this application are provided for consistency with the parts of an application suggested under 37 CFR 1.77 or otherwise to provide organizational cues. These headings shall not limit or characterize the invention(s) set out in any patent claims that may issue from this application. Specifically and by way of example, although the headings refer to a "Field of the Invention," the claims should not be limited by the language chosen under this heading to describe the so-called field of the invention. Further, a description of a technology in the "Description of Related Art" is not be construed as an admission that technology is prior art to the present application. Neither is the "Summary of the Invention" to be considered as a characterization of the invention(s) set forth in the claims to this application. Further, the reference in these headings to "Invention" in the singular should not be used to argue that there is a single point of novelty claimed in this application. Multiple inventions may be set forth according to the limitations of the multiple claims associated with this patent specification, and the claims accordingly define the invention(s) that are protected thereby. In all instances, the

scope of the claims shall be considered on their own merits in light of the specification but should not be constrained by the headings included in this application.